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ORIGINAL PAPER

Evaluation of the adaptability and response of indigenous trees to assisted rehabilitation on the degraded hillsides of Kuriftu Lake Catchment (Debre Zeit, Ethiopia)

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Abstract : Removal of trees and shrubs from hillsides exposes a site to erosion that threatens soil aggregation and stability. The present study aimed at evaluating the performance of five indigenous tree species in rehabilitation of degraded hillsides of Kuriftu Lake Catchment and the role of water harvesting structures. Adaptability varied by tree species and water harvesting structures significantly augmented seedling establishment for some tree species. Height of *Acacia abyssinica* planted on steeper slopes (18%–27%) without infiltration pits was lower than for conspecifics planted with infiltration pits. *Dodonaea angustifolia was* proved to be best adapted to the site and showed no need for water harvesting regardless of planting position across the degraded hillside. Planting of *Acacia seyal* should be restricted to gentler slopes (0–17%) with infiltration pits: tree height declined significantly on steep slopes without infiltration pits. *Olea africana* performed better on gentle slopes with pits but also grew well on steeper slopes with pits. *Euclea schimperi* was proved to be least effective of the species evaluated in this study.

Keywords: Infiltration pits, Kuriftu Lake catchment, water harvesting

Introduction

The Ethiopian landscape is characterized by chains of high mountains, rift valleys, plateaus and flat plains. Elevations range widely over short distances from 110 m asl to 4620 m a.s.l. Rivers cross the high mountains resulting in small to huge rifts and enormous plateaus. In addition to regional patterns of rainfall and temperature local climates are affected by the rain-shadow effect of mountains. Annual rainfall in Ethiopia varies on average from100 mm in the lowlands to 2,800 mm in the highlands.

Many hillsides in the Ethiopian highlands have been degraded by excessive harvest by smallholder farmers of firewood and food. These hillsides are commonly owned and their management and rehabilitation has been complex. A study conducted in Northern Wello, Ethiopia demonstrated, however, that with sufficient seed sources in surrounding remnant vegetation and in the soil seed bank, natural regeneration is a potential solution to rehabilitate degraded hillsides. If natural regeneration cannot be effected, degraded hillsides can be reforested by plantation using tree species that can withstand local site conditions (Singh et al. 2012).

Among the major lakes of potential scenic value in the Ada Liben woreda, East Shoa zone of Oromia is Lake Kuriftu with a total area of 4 ha at an elevation of 1,883 m a.s.l. The lake is located at 8°46′28″N and 39°00′38″E (Fig. 1). Total annual rainfall at the lake is 745.6 mm (station record), which is adequate for normal tree growth and establishment. The soil in the study area is characterized as Vertic Andosol, a very fine textured soil of volcanic origin and the most productive soil type of Ethiopia gave adequate supply of water (Mesfin 1998). Although annual rainfall is sufficient to maintain tree growth, soil moisture and soil depth are concerns due to the typically shallow soils and poor moisture storage conditions on the study area.

Soils on hillsides that are devoid of vegetation are subject to accelerated soil erosion since the intensity of runoff increases with gradient. Unwise utilization of soils results in the loss of the productive potential of soil. The severity of erosion depends on a combination of many factors, including the amount and intensity of precipitation, soil texture, slope steepness, and the amount of ground cover (Hillel 1998).

Slope gradient controls runoff and drainage, and hence affects the water content of soils (Toumey 1974). Soil depth and moisture content vary almost directly with gradient when other conditions are held constant. For successful rehabilitation of hillsides such as those at Kuriftu Lake catchment there should be a

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mechanism to enable water infiltration and increase soil moisture content, and thereby contribute to tree establishment and growth. Water harvesting is the collection of runoff for productive purposes as opposed to leaving it to cause erosion (FAO 1991). In semi arid and drought-prone areas, it is a productive form of soil and water conservation. In semi-arid areas, rainfall is often accompanied by large amounts of surface runoff. Thus it is important to use the limited amount of rainfall as efficiently as possible. One way to do this is to use surface runoff by water harvesting. Another is to encourage infiltration and storage of rainwater (Anschutz et al. 2003).

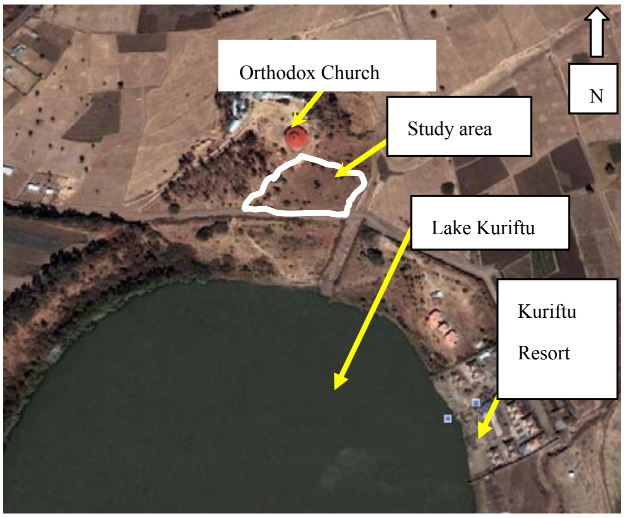

Fig. 1. Kuriftu Lake Catchment and the study area. Sources: http://www.maplibrary.org/stacks/Africa/, Google Earth.

Apart from some minor uses for recreation and water supply, the potentials of Kuriftu Lake have not been fully utilized in an environmentally friendly approach. Due to severe soil degradation caused by human infringement, few naturally growing trees remained on the hillsides surrounding the lake. Information was inadequate on the tree species potentially useful for reforestation the hillsides, particularly with respect to moisture stress and shallow soil depths. Knowledge of integrating water harvesting with tree planting on hillsides was also not available although this concept was not new to the area. In contrast, in the highlands of Ethiopia where natural resources are highly threatened due to decades of unsustainable farming of marginal hills, treatments are widely practiced to restore degraded sites. Treatments of watersheds are designed to slow surface flows to increase infiltration. These include construction of Continuous Contour Trenches (CCT) or hillside terraces, stone bunds, soil bunds and contour vegetation strips. These practice result in control of soil erosion, retention of soil fertility, and increased soil moisture, infiltration and groundwater recharge. Construction of stone bunds or stone-faced trench bunds, for example, is widely adopted by many farmers in Ethiopia to retain rainwater and reduce runoff that causes erosion. These technologies are water harvesting practices intended to store rainwater for crop production and enhance groundwater recharge. The technology originated in India and has been practiced in the Blue Nile basin, the Tigray region, North Shoa and the Awash basin of Ethiopia (SLMP 2010; Zemadim et al. 2011).

Continuous Contour Trenches (CCT) is also promoted by the extension service in Ethiopia because CCTs do not require the use of stones and are positively rated by farmers (SLMP 2010). Though these systems are increasing productivity in the highlands, they lack basic elements of water harvesting structures like cross ties and infiltration pits that facilitate surface water infiltration and increase the availability of moisture near at the rooting zone, thereby increasing seedling survival in semi arid areas such as the Kuriftu Lake catchment. Problems arising from hillside soil erosion and land degradation in the study area stimulated this research to identify plantation tree species and water harvesting techniques that could be used for future rehabilitation options. We evaluated five indigenous tree species, *viz*. *Acacia abyssinica*, *Euclea schimperi*, *Olea africana*, *Dodonaea angustifolia* and *Acacia seyal*, for their adaptability on 0.25 ha land for five years. The objectives of our study were: (1) to evaluate the adaptability of indigenous tree species for plantation; and (2) to evaluate the role of water harvesting structures in reforestation of degraded hillsides.

Materials and methods

There are many indigenous tree species whose environmental requirements match the conditions of the study area. We selected the five species listed above based on two environmental parameters, total annual rainfall and temperature. We classified the hillsides in two slope gradient classes. Because slope gradient controls runoff and water infiltration, thereby impacting seedling establishment, it was considered the first factor (factor 1) with the two different gradient classes as its levels.

Continuous contour trenches or hillside terraces are practiced in low to high rainfall (250 to 3,000 mm) regimes, and on mild to steep slopes (5 to greater than 60% slopes). The technology reduces the speed of flowing water, traps rainwater and enables it to percolate to aquifers (Zemadim et al. 2011). The two slope classes identified for this research were slope class I (0−17%) and slope class II (18%−27%). Slope class I had thicker soils and better micro-site conditions while the slope class II was relatively degraded with shallow soils and poor micro-site conditions. Slope gradients were measured using an impulse hypsometer that operates through generation of IR radiation.

Tree species was assigned as factor 2. Tree species vary in their capacity to survive a given set of site conditions. Accordingly, the five tree species listed above were considered as levels for the factor 2.

The third factor considered for the research was water harvesting structure. In semi-arid areas, rainstorms are usually heavy and soils generally cannot absorb the amount of water that falls during short rainfall events. As a result, rainfall in semi-arid areas is often accompanied by surface runoff. These climatic characteristics of semi-arid regions dictate the importance of efficient use of rainfall. One way to do this is water harvesting.

Another is to encourage infiltration and storage of rainwater i.e. soil moisture retention or conservation (Anschütz et al 2003). Based on this fact the five evaluated tree species were planted as seedlings with and without infiltration pits on the two slope classes. The third factor had two levels, i.e. level zero referred to plantings without infiltration pits and level one referred to plantings with infiltration pits.

Contour bunds for trees are the most simplified form of micro catchments for better soil and moisture conservation (FAO 1991), and were constructed along contours over the entire study area (Fig. 2). As the name indicates, the bunds followed topographic contours at close spacing, and by provision of small earth ties (cross ties) the system was divided in to individual micro catchments. Contour bunds were made by digging a furrow along the alignment following a somewhat curved path and heaping the soil down slope. This was followed by compaction and stabilization of the structure by planting grasses and construction of infiltration pits of dimension 40 cm×40 cm×20cm in each micro catchment.

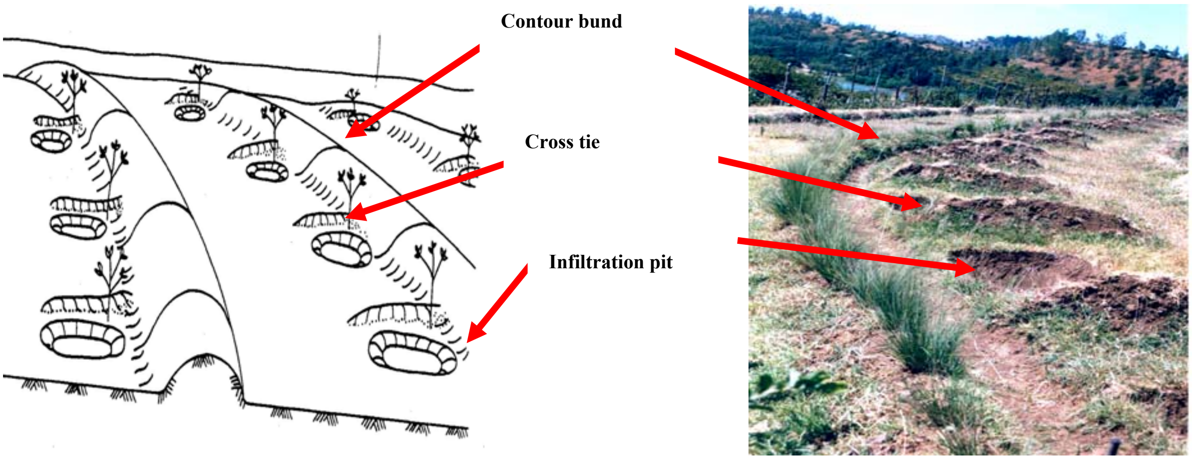

Fig. 2. Alignment of Bunds, infiltration pits and Cross ties constructed in the field (Kuriftu Lake catchment- June 2004)

Line level technique was used to bring alignment of the bunds along the contour. Bund height was at least 25 cm on lower slope classes and 30 cm on higher slope classes, based on recommendations for arid and semi-arid areas.

The study area was divided into three blocks. The experimental design used was split-split plot. Slope was assigned as main plot factor with its levels S1 and S2. Water harvesting structure (with levels H 0 and H 1) was a sub-plot factor and species type (with levels A, B, C, D, E) was a sub-sub-plot (split-split plot) factor. This resulted in 3 blocks (I-III) each with 2 main plot treatments (S1 and S2) attached to 2 sub-plot treatments (H 0 &H 1) and this combination was further attached to 5 treatments, i.e. the five tree species for evaluation (A-E) in split-split plots. The assignment of treatments and levels was carried out through step wise randomization procedure of the split-split plot design with three replications (Fig. 3).

Pure, viable seeds of the selected tree species were collected and their seedlings were raised in the nursery at Debre Zeit Agricultural Research Center using standard procedures and substrate mixtures in June 2004, the year prior to the onset of field work. Seedlings were raised for 7−10 months in the nursery until they attained heights of about 40 cm. 15 seedlings of each species were planted on plots of about 50 m^2 across the slope at a spacing of 1.5 m and in the space between the infiltration pit and the crosstie (Fig. 4). Planting was carried out after the first runoff was harvested.

We recorded tree height, collar diameter, and survival at five years after planting. The raw field data were then summarized by mean values of 15 trees per plot per species for the variables mentioned above and then transferred to data summary sheet of split-split plot design prior to subsequent analysis using statistical software. Data collected on survival, height and diameter of trees starting from the onset of the dry season were then subjected to statistical analysis (ANOVA) to assess differences between treatment means at α=0.05. Survival count data were log transformed to approximate normality before parametric testing.

Results

The study proved significant differences in mean height and diameter growth among species tested on the hill side of the study area at =0.05. Evaluated tree species showed significant variability of height and diameter performances in lower and higher slope classes (Fig. 5). The decline in performance of some species in higher slope class (due to poor moisture conditions) was proved to be redeemed through the use of water harvesting structures. Mean height and mean diameter of *A. abyssinica* grown with infiltration pits were significantly greater than for all other combinations of species and treatment (Fig. 6, 7). *Dodonaea angustifolia* proved to perform equally comparably in higher slope classes (where the soil is shallow and moisture is

limiting) without infiltration pits as in lower slope classes with pits. This signified its relative moisture stress tolerance (Fig. 8).

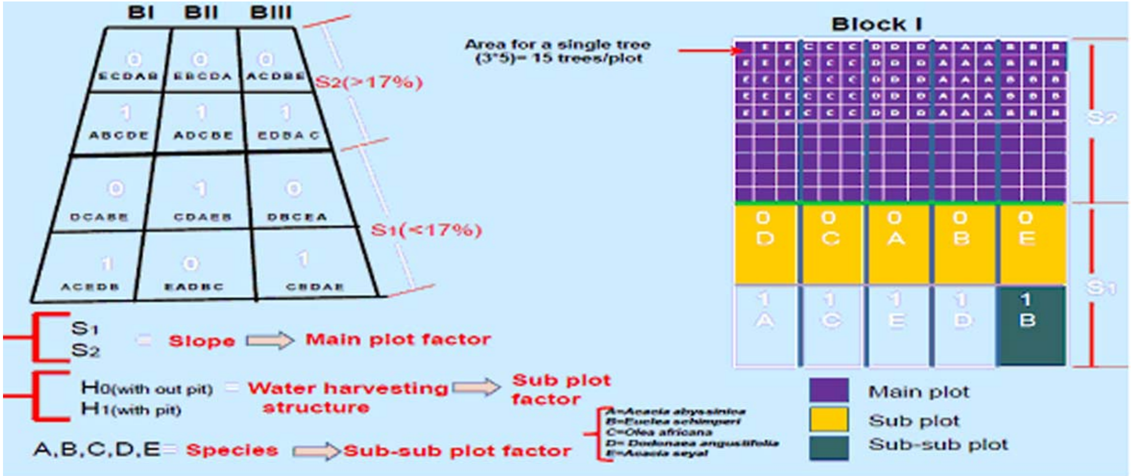

Fig. 3. Field layout and randomization of treatments. (A is *Acacia abyssinica*, B is *Euclea schimperi*, C is *Olea Africana*, D is *Dodonaea angustifolia*, E is *Acacia seyal*).

Fig. 4. Essential structures for water harvesting in the field (two years after planting): (a) *Acacia Abyssinica* (b) *Dodonaea angustifolia* (c) *Acacia seyal* and (d) *Olea africana*.

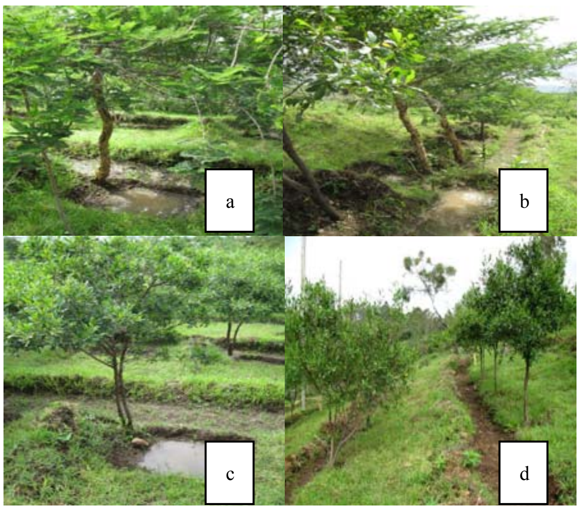

Fig. 5. Trees species under varying planting conditions (3years after planting) (a). *Acacia abyssinica* with pit- slope class I. (b) *Acacia abyssinica* with pit –slope class II. (c). *Dodonaea angustifolia* with pit- slope class I. (d). *Dodonaea angustifolia* without pit –slope class II.

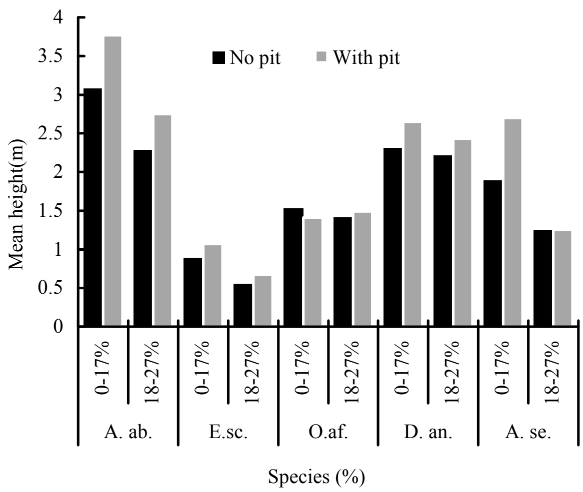

Fig. 6. Height distribution of evaluated tree species

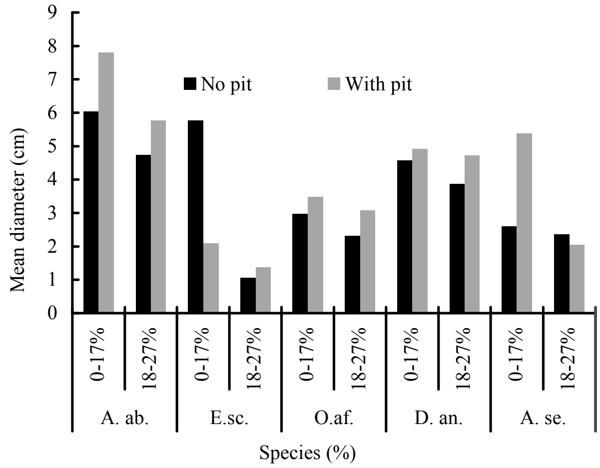

Fig. 7. Diameter distribution of evaluated tree species

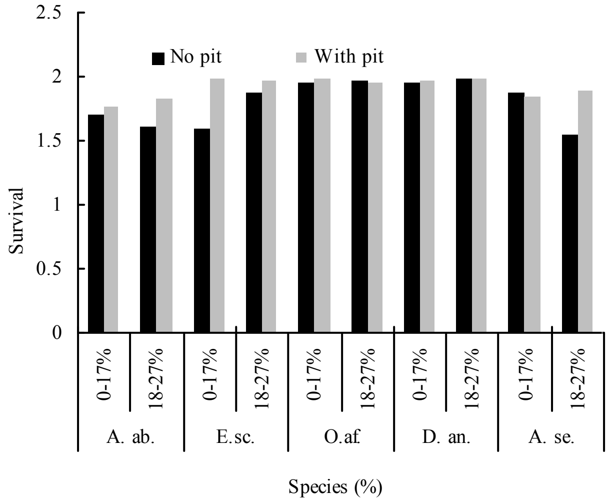

Fig. 8. Survival distribution of evaluated tree species

The use of pits in higher slopes for *Olea africana* proved a closely comparable mean height and diameter to its counterparts in lower slopes (Table 1). Thus the use of pits would be recommendable for this species in higher slopes. Planting *Acacia seyal* in higher slopes without pits resulted in a significantly lower height and diameter that could not be redeemed through the use of pits Mean height and mean diameter of *Euclea schimperi* were the least for all combinations of treatment.

The species with significantly higher diameter and height like *Acacia abyssinica* gave rise to relatively lower survival. This was mainly attributed to stem decay disease the cause of which is under scrutiny (Table 1). The disease selectively attacked *A. abyssinica* around four years of age after planting. *Euclea schimperi* with the least height and diameter performance gave rise to a highly significant survival equally comparable to *Dodonaea angustifolia* and *Olea Africana* (Table 1).

Table 1. Multiple mean comparison of height, diameter, and survival

Species	Slope class	Pit/No pit	Height (m)	Diameter (cm)	Survival
Acacia abyssinica	I	0	3.08(b)	6.03(ab)	1.703(abcd)
		1	3.77 (a)	7.81(a)	1.760(abcd)
	II	0	2.28 (cd)	4.73(bcde)	1.613bcd)
		1	2.75 (bc)	5.77(bc)	1.830(abc)
Euclea schimperi	I	0	0.89(ghi)	1.64(hi)	1.590(cd)
		1	1.07(ghi)	2.09(ghi)	1.980(a)
	II	0	0.55(i)	1.05(i)	1.873(ab)
		1	0.67(hi)	1.39(hi)	1.967(a)
Olea africana	I	0	1.53 (efg)	2.97(efghi)	1.957(a)
		1	1.41(efg)	3.48(defgh)	1.977(a)
	II	0	1.41(fgh)	2.31(ghi)	1.967(a)
		1	1.49(efg)	3.08(efghiI)	1.957(a)
Dodonaea angustifolia	I	0	2.31(bcd)	4.57(bcdef)	1.957(a)
		1	2.65(bcd)	4.92(bcde)	1.967(a)
	II	0	2.21(cde)	3.87(cdefg)	1.990(a)
		1	2.43(bcd)	4.73(bcde)	1.977(a)
Acacia seyal	I	0	1.89(def)	2.59(fghi)	1.873(ab)
		1	2.70(bc)	5.38(bcd)	1.837(ab)
	II	0	1.25(fghi)	2.35(ghi)	1.547(d)
		1	1.25(fghi)	2.05(ghi)	1.890(ab)

Notes: Slope class I is 0−17%; Slope Class II is 18%−27%; (0) is Seedlings without pit; (1) is Seedlings with pit; Different letters in the height, diameter, and survival columns indicate that means are significantly different at alpha 0.05. LSD for height is 0.68. Standard error of the mean for Height is 0.240 at alpha 0.050. LSD for diameter is 1.79. Standard error of the mean for diameter is 0.628 at alpha 0.050. LSD for survival is 0.24. Standard error of the mean for survival is 0.085 at alp. 0.05.

Discussion

According to Blanko and lal (2008), restoration refers to the process of repairing and returning damaged or degraded soils to a condition similar to the pre degradation level of capability for supporting plant growth and maintaining environmental quality.

This study proved the best performing tree species for successful restoration of the degraded hills at Kuriftu. It was also found out that tree species have significantly differing performances in their response to management or earthwork practices. The performance of some species was less influenced by their planting location across the slope as well as by the presence or absence of infiltration pits.

The study proved that regardless of its planting locations across the slope, infiltration pits are prerequisites for significantly better performance of *Acacia abyssinica* while the use of pits across the slope is not crucial for *Dodonaea angustifolia*. This would suggest that *Dodonaea* is relatively hardy towards poor soil moisture conditions. Tesfaye (2000) also argued that Dodonaea is a promising species to colonize barren areas suggesting that it could be used at early stages of restoration before reintroduction of other late successional species.

Planting *Acacia seyal* should be restricted to lower slopes with infiltration pits for it was found out to be less tolerant to highly moisture stressed site conditions of up slopes where the soil is relatively shallower. This was disclosed by a significant decline in its height and diameter performance in higher slopes though it was assisted with infiltration pits. On top of survival the ecological role that a species play counts a lot especially in the rehabilitation degraded hill sides and this is typically linked with growth and enlargement of the species under consideration. Thus even though *Euclea schimperi* revealed comparably higher mean survival value over the best performing tree species like *Acacia abyssinica*, *Olea africana* and *Dodonaea angustifolia*, it would be the least preferred for the rehabilitation of the study area due to its very low height and diameter performance.

Conclusions and recommendations

The evaluation study revealed significant performance differences among evaluated tree species. It also indicated the role that water harvesting structures play in enhancing the performance some tree species.

In conclusion, this study recommends that for future rehabilitation tasks in similar areas *Dodonaea angustifolia* should be planted without pits regardless of its location across the slope for significantly higher performance. It would be highly recommendable to plant *Acacia abyssinica* with infiltration pits both in higher and lower slopes for it is relatively less moisture stress tolerant. Though *Olea africana* is relatively hardy after establishment, it is recommended to assist this tree species with infiltration pits in higher slopes to acquire a comparable performance as to lower slopes. On the other hand, planting of *Acacia seyal* should be restricted to lower slopes with infiltration pits for it was found out to be less tolerant to highly moisture stressed site conditions of up slopes.

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